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THE OUM SOUID WETLAND: SPATIAL VARIABILITY, MODELLING OF SOIL-WATER PROPERTIES AND ECOLOGICAL IMPORTANCE

Abstract: As a first study, soil and water properties of the Oum Souid wetland, a lake far west of the Ghardaïa region (Algeria), were investigated. Despite its ecological, tourist, and socio-economic importance, the wetland is little known, as it is situated in a biotope with an arid bioclimate among dune formations. Flora and avifauna inventories were conducted in the wetland to assess the studied site's characteristic biodiversity. Vertical profiles from 0 cm to 90 cm deep were sampled. Fifty samples from each soil were prospected for organic matter, electrical conductivity (*EC*) and pH. Additional characteristics describing neighbouring water samples, including dissolved oxygen (DO), electrical conductivity (*EC*), and pH, were also determined in situ. The census of bird and plant species revealed a biological richness, with 12 families of migratory birds and 21 botanical families identified. Soil analysis indicated a sandy-clay texture with little silt for all the profiles. However, some profiles were marked by a sandy-clay-loamy texture. The assessment of spatial variation revealed a moderately alkaline soil pH, high electrical conductivity, and fairly organic matter content. Water samples were characterised by a strongly alkaline pH, slight salinity, and a high dissolved oxygen rate. These findings underline the crucial role of the Oum Souid wetland as a biodiversity refuge within the Saharan environment and highlight the need for integrated, sustainable land management strategies to ensure the long-term conservation of its ecological functions and natural heritage.

Keywords: soil, water, spatial variability, Oum Souid wetland, Ghardaïa, Algeria

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Introduction

Arid zones occupy 43 % of the Earth's surface, producing extremely edapho-climatic conditions [1, 2]. They are generally found on all continents but are much more concentrated in Asia and Africa [3]. Although the northern Sahara's climate is harsh and characterised by complex and extreme conditions, it contains several wetlands whose hydrological systems are variable (spatiotemporal) compared to its drier environments [4, 5].

The most economically valuable ecosystem and among the richest in the world for biodiversity, they are disappearing three times faster than forests. This ecosystem is defined as transitional areas between terrestrial and aquatic systems where the groundwater is close to or reaches the soil surface or where this surface is covered by shallow water [6]. Algeria hosts 2,375 wetlands, including 50 Ramsar sites, comprising 2056 of natural origin and 319 of artificial origin [7]. However, it also contains many unclassified and unidentified wetlands, especially in the Sahara, which are considered biotopes for several species of flora and fauna highly adapted to harsh conditions [8, 9].

Significant global climate changes and intensified human activity are dramatically impacting ecosystems. The Sahara has a characteristic arid climate, with its water resources dispersed in markedly unbalanced amounts. In recent years, soil degradation and recurrent extreme weather events have rendered the natural environment in dry zones increasingly vulnerable [10-12]. Lake biodiversity, regarded as a metasystem, is significantly influenced by hydrological conditions, structural and functional attributes, and their relative placements within the landscape. However, the function of lakes as indicators of the Earth's response to climate change is a significant focus for the United Nations' Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) [13, 14].

Among these unclassified and unidentified wetlands, the Oum Souid wetland, which is located at the terminal limit of Zergoune Valley, bordering El-Anagueur erg to the south of Mansoura (Province of Ghardaïa), serves as a refuge for a significant number of fauna and flora species. While it covers an area of 600 hectares and is a storehouse for diverse plant and animal species of ecological interest, it remains little known due to the rarity of studies conducted in this region.

However, no previous research has assessed the physicochemical properties and biodiversity of the Oum Souid wetland. Using a cartographic approach, this study aims to evaluate the spatial variability of soil and water parameters and their ecological implications in biodiversity conservation.

Material and methods

Study area

The Oum Souid wetland, with its coordinates 2°33'45.33"E, 32°17'27.96"N, is located at the terminal limit of the Zergoune Valley (bordering El-Anagueur Erg), far west of the Ghardaïa Province, which is part to the west of the Mansoura and the south of the Metlili town (160 km), while it covers an area of 600 hectares immersed by freshwater to a depth ranging from 0.5 m to 1.5 m depending on the season. This location serves as a refuge for many fauna and flora species. It is also a storehouse for diverse plant and animal species of ecological interest. It remains little known due to the rarity of studies conducted in this region (Fig. 1).

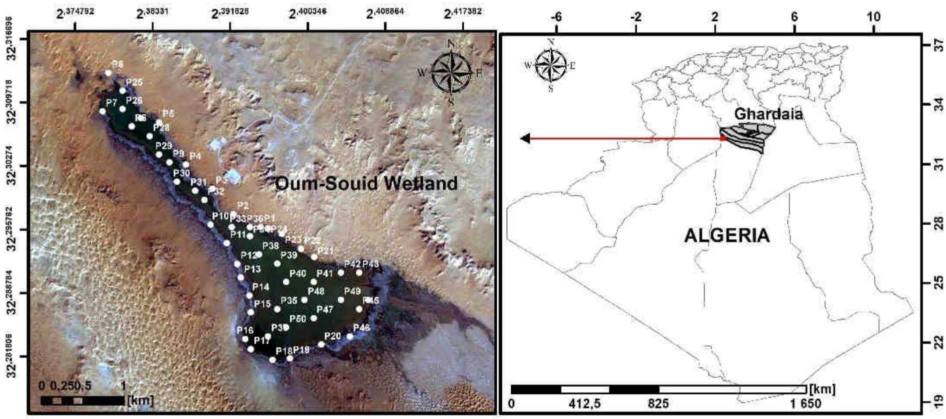


Fig. 1. Map of study area (Oum Souid wetland) and soil-water sampling

Sampling design and processing

Monitoring aquatic birds is based on repeated counts at a trimestral rhythm. The counts were conducted through direct observation using a telescope (20 x 50) mounted on a tripod and a camera. Similarly, a group of floristic surveys had been performed in three stations, composed of sub-stations of 100 m^2.

Three soil horizons (0 cm - 30 cm, 30 cm - 60 cm, and 60 cm - 90 cm) were randomly sampled using a 1.20 m auger. Fifty samples were taken in a composite manner from each soil level. The soil samples were dried and sieved before being analysed. Organic carbon levels of soil samples were determined by the modified Walkley-Black (WB) dichromate method [15]. *EC* and pH were measured using 1/5 ratios (soil/water) [16]. The hydrometer method determined soil texture [17].

To explain potential water-soil relationships, water analyses of adjacent areas were also conducted for fifty samples (50) of the same geographical location as the soil samples. DO concentrations, an important water quality indicator, were in situ measured. Electrical conductivity and pH were determined using an electrochemical sensing instrument.

Statistical and geostatistical analyses

The variability maps were obtained after auto-kriging parameters under R 3.4.2, using an automated function (autoKrige) to determine the best-fit variogram parameters and perform kriging interpolation. Once the best model is selected, the software performs kriging interpolation to predict values at unsampled locations and the thematic maps were created using QGIS 3.34.9 (Table 1). Experimental data were subject to a statistical approach based on the multivariate generalised linear model (MGLM) using R 4.3.2, to study the effects of the randomised factor (horizon) at a significant level $\alpha = 0.05$, in which soil parameters were fitted according to the Gaussian distribution family and identity link. Thus, the Principal Component Analysis (PCA) and the multiple correlation matrix were developed to identify the most significant correlations.

Table 1

Fitted variogram models and variation of soil-water properties

Parameter	Horizon [cm]	Model	Nugget	Sill	Range	Coefficient of variation [%]
Soil						
EC [μS/cm]	0-30	Spherical	0	1688225	680	76.22
	30-60	Spherical	0	2544251	583	78.37
	60-90	Gaussian	0	3710591	206	89.76
OM [%]	0-30	Exponential	0.28	0.75	7515	45.97
	30-60	Exponential	0.27	0.49	5608	62.07
	60-90	Spherical	0.15	0.32	315	70.05
pH [-]	0-30	Gaussian	0	0.18	235	5.28
	30-60	Gaussian	0.06	0.11	435	3.98
	60-90	Spherical	0.03	0.14	595	4.46
Water						
DO [mg/L]	/	Exponential	163473	1122463	8432	47.41
EC [μS/cm]	/	Spherical	0	3485	10	6.46
pH [-]	/	Spherical	0.1	0.2	972	5.82

Results

Fauna and flora diversity

The total species richness collected estimates 63 bird species belonging to 12 families. The species from the families *Anatidae* and *Scolopacidae* are the most dominant. In the same context, 79 plant species belonging to 21 botanical families have been identified. Only one or two species represent some families, while others contain several floristic species, with a predominance of the *Brassicaceae* and *Poaceae* families (Fig. 2).

Field description and soil properties

The topography analysis shows that the Oum Souid wetland has an elongated geographical depression shape from the northeast towards the southwest between 570 m and 534 m and from the northwest to the southeast, with altitudes of 546 m and 551 m. This indicates and explains the formation of its basin, thus confirming that this area is a portion of the valley. As reported in Table 2, granulometric analysis on specific soil samples revealed a sandy-clay texture with little silt for most of the profiles. Nevertheless, a sandy-clay-loamy texture marked some profiles (Fig. 3).

Table 2

Granulometric characteristics and soil description of some profile prospected

P5	P3	P18	P19	P17	P21
0 cm to 10 cm Beige silty sands	0 cm to 90 cm Dark brown clayey-silty sands	0 cm to 5 cm Brown clayey-silty sands	0 cm to 30 cm Light gray silty sands	0 cm to 25 cm Dark brown clayey-silty sands	0 cm to 50 cm Brown silty sands
10 cm to 87 cm Brick-red silty sands		5 cm to 90 cm Light black silty Sands	30 cm to 90 cm Light yellow Silty sands	25 cm to 60 cm Beige clayey-silty sand	50 cm to 60 cm Dark brown clayey-silty sands
87 cm to 90 cm Beige clayey-silty sand				60 cm to 90 cm Beige silty sands	60 cm to 90 cm Dark brown silty sands

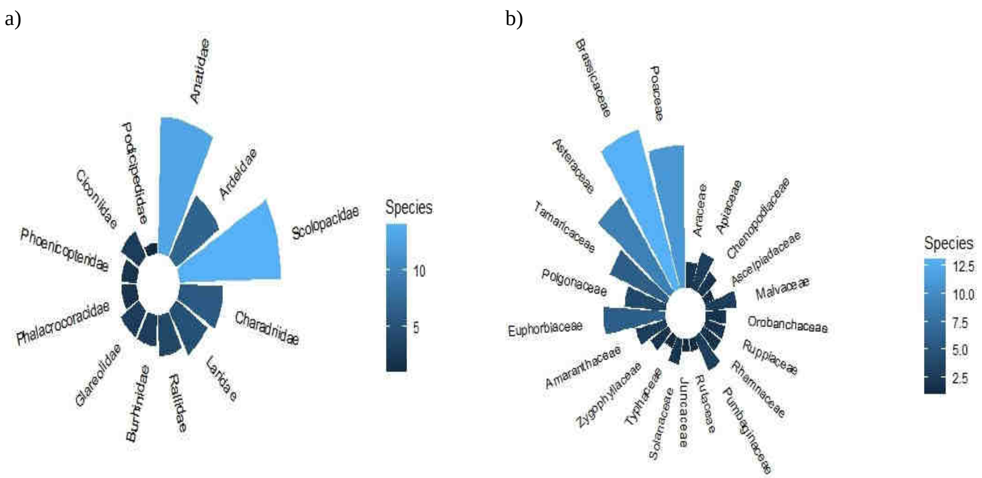


Fig. 2. Circular barplot illustrating the distribution of species depending on taxonomic family: a) bird's diversity, and b) plant diversity

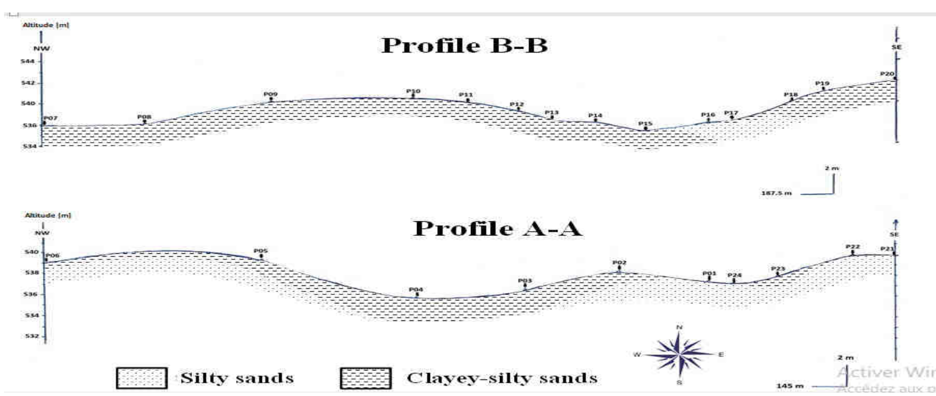


Fig. 3. Topography analysis of the Oum Souid wetland. Profile A-A from the northeast towards the southwest. Profile B-B from the northwest to the southeast of the wetland

The results of soil data modelling from the MGLM model reveal a significant effect of the sampling level factor (horizon) on organic matter, but not for pH and EC. Indeed, the soil characterising the 0 cm - 30 cm horizon is moderately alkaline, reaching a maximum pH of 8. The slightly alkaline soil extends over a few locations in the western part of the wetland area. The evaluated coefficient of variation of 5.28 % in this horizon highlights a low variability among all the pH values. This is the case for the 30 cm - 60 cm horizon, where moderately alkaline soils are the most dominant, and slightly alkaline soils are located on the lake's western side. However, for the 60 cm - 90 cm horizon, strongly alkaline soils were identified in the northwest with a pH exceeding 8.4 and predominance of moderately alkaline soils (Fig. 4).

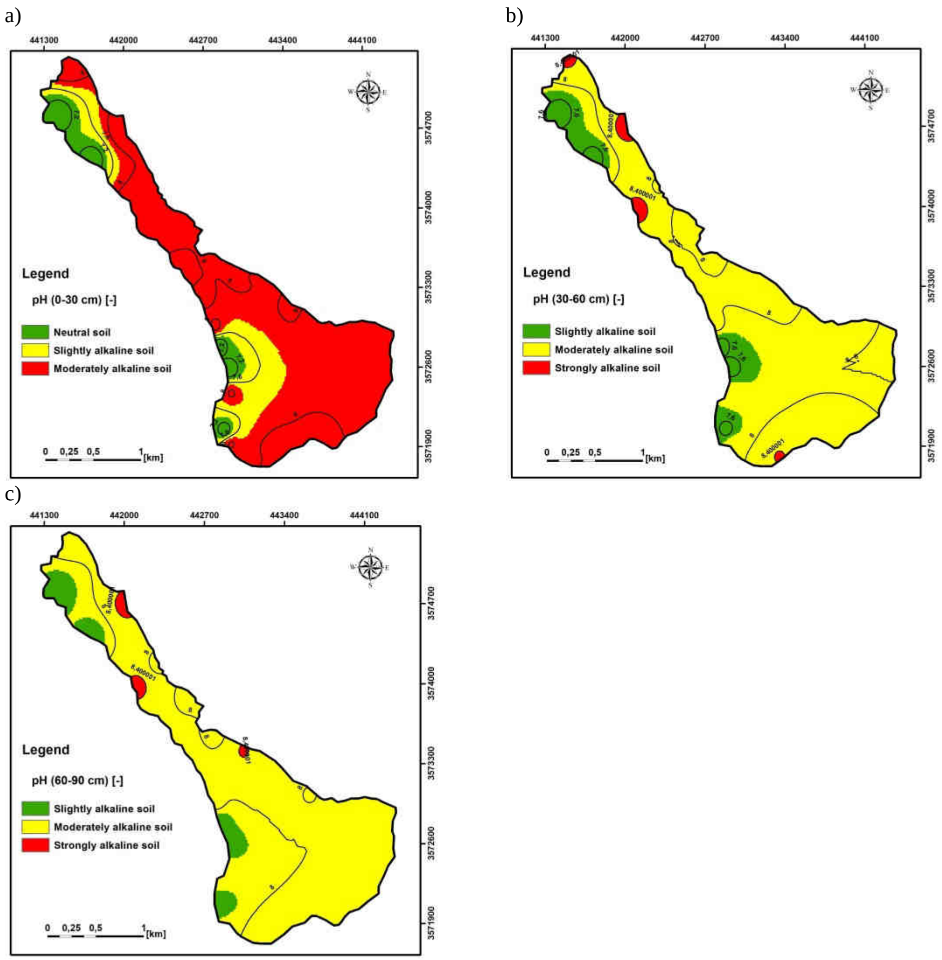


Fig. 4. Map of spatial variability for pH of soil depending on profiles: a) variation of pH values on 0 cm - 30 cm, b) variation of pH values on 30 cm - 60 cm, and c) variation of pH values on 60 cm - 90 cm

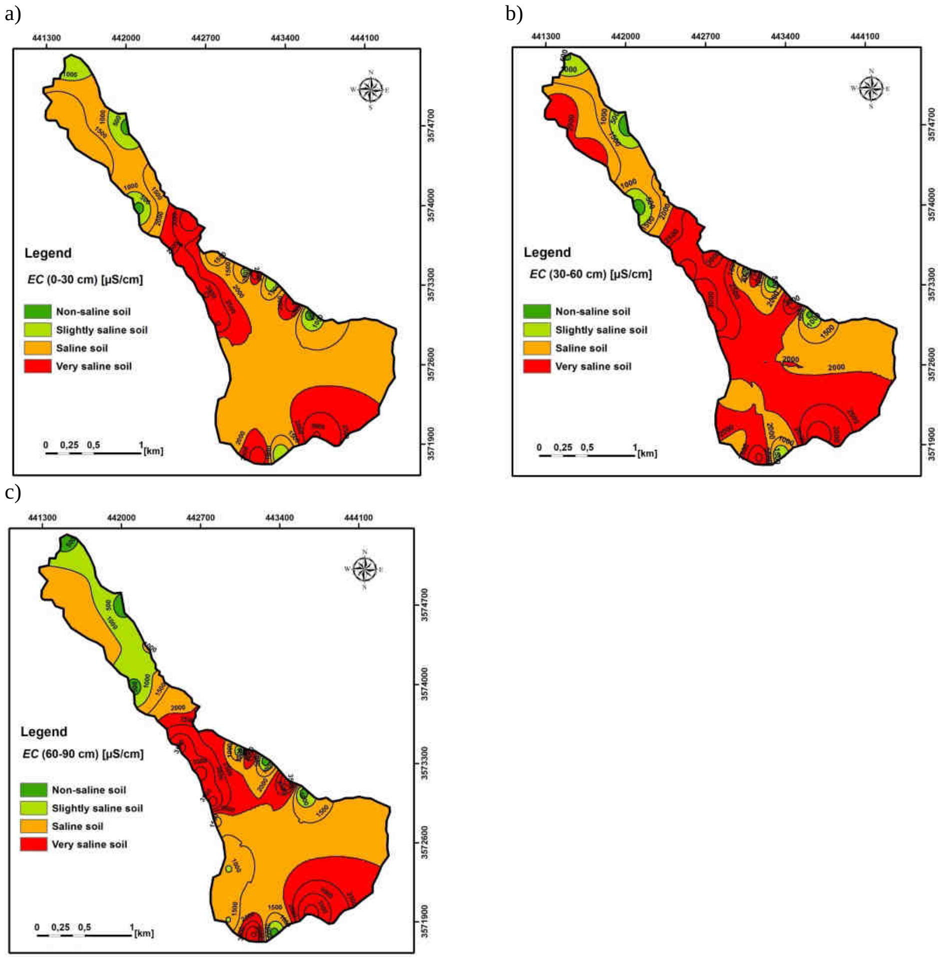


Fig. 5. Map of spatial variability for *EC* of soil depending on profiles: a) variation of *EC* values on 0 cm - 30 cm, b) variation of *EC* values on 30 cm - 60 cm, and c) variation of *EC* values on 60 cm - 90 cm

Data related to electrical conductivity show that salty and very salty soils predominate throughout the wetland and for all the examined horizons. It was even more significant, oscillating between 2500 µS/cm and 3000 µS/cm at the 30 cm - 60 cm horizon, with a very high variability noted (76.22 %). Non-saline or slightly saline soils occupy only small wetland areas, particularly in the northwest. Nevertheless, it is at the 60 cm - 90 cm horizon that electrical conductivity values exceeding 3500 µS/cm were recorded (Table 3) (Fig. 5).

The assessment of spatial variation indicates a decreasing gradient in organic matter richness, increasing as one moves from the surface layer to the deeper layers. At the surface layer (0 cm - 30 cm), soils moderately rich in organic matter spread over most of the studied geographical area. The organic matter rate becomes low for the northwest region compared to the southern region in the 60 cm - 90 cm layer. Soils are predominantly poor in organic matter at the deepest layer (60 cm - 90 cm). However, soils rich in organic matter (> 3 %) occupied only restricted areas scattered across all layers (Fig. 6).

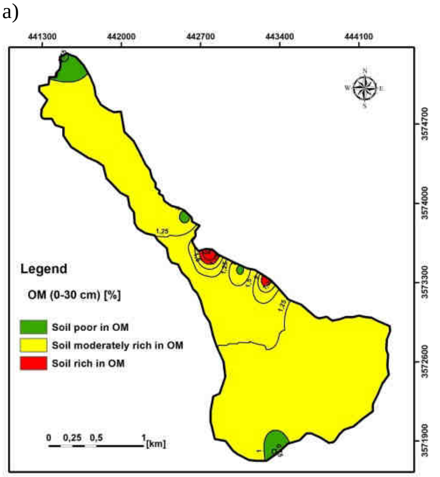
Table 3

Statistical data based on soil properties depending on profiles using the Multivariate Generalised Linear Model

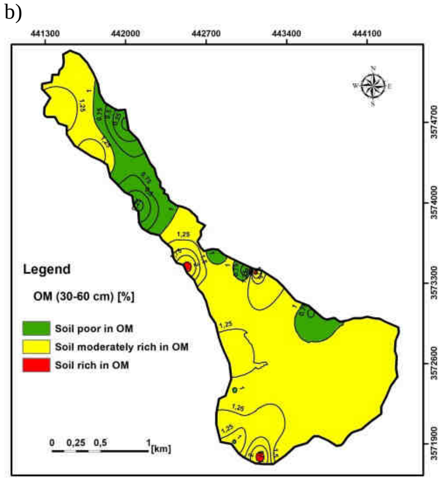
Predictors	**pH [-]**		***EC* [µS/cm]**		**OM [%]**	
	Estimates	**CI**	**Estimates**	**CI**	**Estimates**	**CI**
(Intercept)	8.10***	7.99 - 8.20	1676.83***	1236.78 - 2116.89	1.11***	0.96 - 1.26
Horizon (30-60) cm	0.06	–0.09 - 0.21	212.31	–410.02 - 834.63	–0.26*	–0.47 - –0.04
Horizon (60-90) cm	0.15	–0.00 - 0.30	283.12	–339.21 - 905.44	–0.25*	–0.46 - –0.04
Observations	150		150		150	
R^2 / R^2 adjusted	0.025 / 0.012		0.006 / –0.008		0.047 / 0.035	

* $P < 0.05$ (significant) ** $P < 0.01$(high significant) *** $P < 0.001$ (Very high significant)

a)



b)



c)

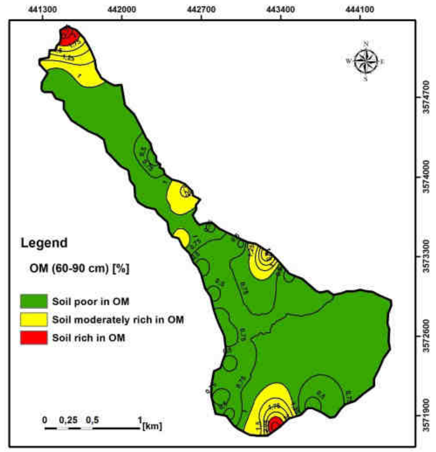
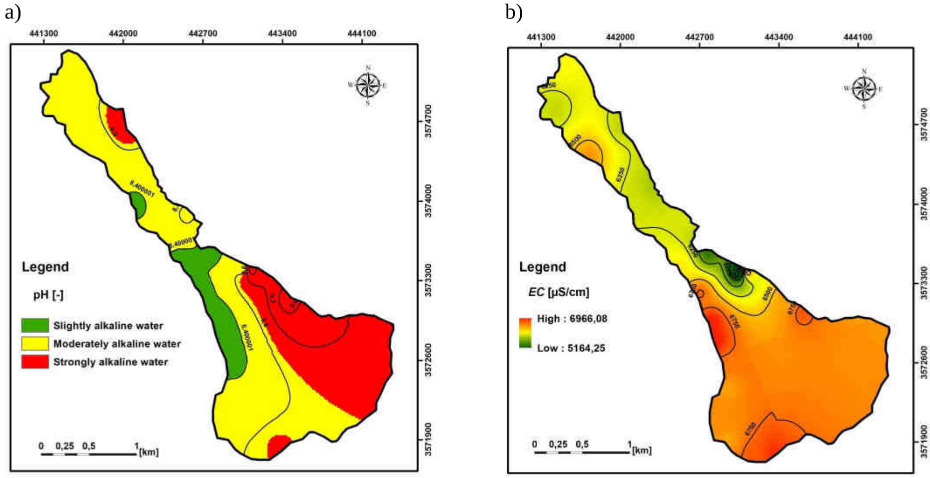


Fig. 6. Map of spatial variability for OM of soil depending on profiles: a) variation of OM values on 0 cm - 30 cm, b) variation of OM values on 30 cm - 60 cm, and c) variation of OM values on 60 cm - 90 cm

Water analyses

The water samples of the wetland show low pH variability (5.82 %). They range from moderately to highly alkaline. In terms of *EC*, the site is divided into two parts: the north, where the waters have low electrical conductivity, and the south, which has high *EC* character. The dissolved oxygen results show a relatively high variability (CV = 47.41 %). Indeed, the lowest oxygen concentration (20.41 mg/L) was recorded at the northern and southern ends of the site, while the highest concentration (89.5 mg/L) was noted in the eastern part of the site (Fig. 7).

a) b)



c)

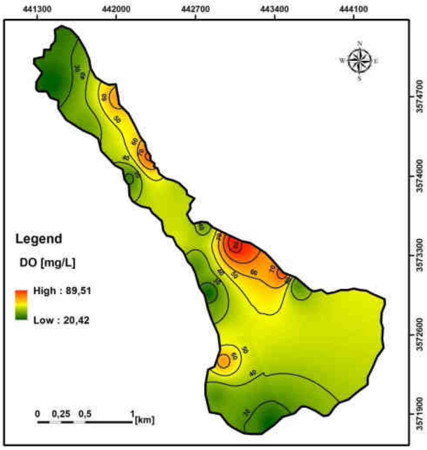


Fig. 7. Map of spatial variability for water properties: a) variation of pH values, b) variation of *EC* values, and (c) variation of dissolved oxygen values

Principal Component Analysis (PCA) and corrplot

The correlation matrix concerning soil characteristics indicated significant positive correlations ($P < 0.001$) among pH values across all assessed soil depths. *EC* demonstrates positive and statistically significant correlations ($P < 0.001$) among the three analysed soil profiles. It is important to note that the sole correlation identified in the water samples is a significant negative relationship between the dissolved oxygen rate and electrical conductivity ($P < 0.01$). A significant negative correlation was observed between water pH and electrical conductivity across all sampled soil horizons ($P < 0.01$) (Fig. 8).

a) b)

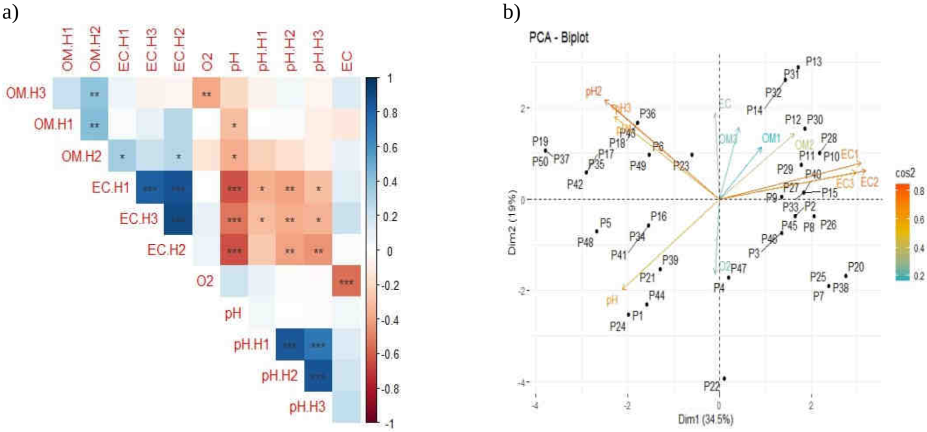


Fig. 8. a) Corrplot illustrating the correlations between soil variables, and water properties, b) PCA-biplot. pH.H1 pH mean in 0 cm - 30 cm, pH.H2 pH mean in 30 cm - 60 cm, pH.H3 pH mean in 60 cm - 90 cm, EC.H1 *EC* mean in 0 cm - 30 cm, EC.H1 *EC* mean in 30 cm - 60 cm, EC.H1 *EC* mean in 60 cm - 90 cm, OM.H1 OM mean in 0 cm - 30 cm, OM.H2 OM mean in 30 cm - 60 cm, OM.H3 OM mean in 60 cm - 90 cm, pH mean pH values of water, EC mean *EC* values of water, O2, dissolved oxygen mean of water samples

Discussion

The Oum Souid wetland is considered a crucial site for migratory passage, stopover, and the wintering of waterfowl [18]. Therefore, wetland vegetation is closely linked to a specific hydrological regime, which ensures the survival of the present species. When this regime is disrupted, whether due to natural changes (like drought) or human intervention, the structure of the vegetation changes, which has a ripple effect on other wild species that depend on the vegetation [19], changes, even subtle ones, in the density or distribution of vegetation can have significant consequences for birds, which often occupy relatively narrow ecological niches [20].

The findings concerning the electrical conductivity of the soils enable the classification of the Oum Souid wetland soils as highly saline [21]. This can be explained by intense evaporation compared to precipitation [22]. According to Li et al. [23], salinisation is due to the geomorphology of the soil during a specific geological period. The salinisation results from the alteration of saline parent rock and the presence of groundwater, which induces very intense salinisation, leading to the formation of brines and salt crusts [24]. Indeed, the nature of soil salinity can vary both quantitatively and qualitatively, not only in the presence of a water body closely related to the dynamics of saline aquifers but also due to the geomorphological and climatic conditions of the region [25].

Furthermore, the electrical conductivity values of the wetland waters show an average of 6465.55 µS/cm, mostly exceeding the indicative range of mineralisation (> 2000 µS/cm), making the water quality potentially elevated/mineralised (depending on natural geology) [26]. According to Mainali and Chang [27], this parameter would be influenced by various natural and anthropogenic factors, such as the geology of the watershed, temperature, water evaporation, and variations in the flow of inputs feeding the lakes and domestic water inputs. It varies with temperature and is closely linked to the concentration of dissolved substances and their nature. However, while mineral salts are good conductors, one must not lose sight of organic and colloidal substances. Consequently, in the case of wastewater, this measurement will not necessarily provide an immediate idea of the saturation of the site's waters [28].

For the pH, the results showed that the Oum Souid wetland soils had a pH ranging between 7.6 and 8.2. According to Bai et al. [29], these values made us consider that they are slightly to moderately alkaline soils. The pH of soils is considered saline when the electrical conductivity is greater than 3000 µS/cm. The salinity becomes neutral due to strong acid and base salts (chlorides, sulfates, sodium, calcium, magnesium) [30]. However, the pH values of the water samples range from moderately alkaline to strongly alkaline (8.8 - 9.6). This can be due to various factors, such as low organic matter or high salinity [31].

Variations in water *EC*, salinity, and alkalinity significantly influence the composition and richness of wetland plant communities. In Mediterranean and North African wetlands, increasing *EC* and high pH are associated with a decline in the diversity of freshwater macrophytes and the progressive dominance of halophytic and alkaline-tolerant species [32, 33]. Research on wetland flora indicates that the interaction of saline and alkaline stress markedly reduces plant growth and survival, confirming that ionic and osmotic stress mechanisms act synergistically to limit freshwater taxa under elevated *EC* and pH conditions [34]. However, in Saharan wetlands of Algeria, bird richness and community composition significantly correlate with salinity gradients, with higher *EC* sites supporting fewer freshwater specialists and an increasing dominance of shorebirds and salt-tolerant species [35]. Similar patterns are observed in Mediterranean wetlands, where elevated salinity and alkalinity simplify trophic structure and reduce vegetation cover, ultimately constraining avian diversity and abundance [36, 37].

The values of the organic matter show that the soil is moderately rich [38]. In general, and according to Alsaleh et al. [39], the organic matter content in arid zones is low (< 1 %). This low content results from the rarity of vegetation and its low biomass. Nevertheless, the spatial variation noted in this present study is related to the vegetation cover characterising the wetland area [40, 41]. However, the organic richness gradually decreases through the profile across the zone. According to Magdoff and Van Es [42], a good organic matter content in sandy soil should be above 11 %.

The specific data on dissolved oxygen shows a concentration of 43.489 mg/l and indicates that the water is of good quality [43, 44], which reports for wetlands that if the concentration of dissolved oxygen is greater than 7 mg/L, the water is considered excellent in this case. According to Larance et al. [45], the amount of oxygen in an aquatic ecosystem depends on natural factors such as temperature, salinity, atmospheric pressure, turbulence, and biological processes. It is accepted that levels below 4 mg/L indicate water of poor quality or polluted [46, 47].

Conclusion

This study has developed a soil and water variability diagnosis from a potentially ecological site, the Oum Souid wetland. It aimed to evaluate the spatial variations of these parameters depending on the sampling profiles collected. The site, presently unclassified, exhibits considerable faunal and floral biodiversity. The most prevalent bird species belong to the families *Anatidae* and *Scolopacidae*. Certain families are represented by one or two species for floral diversity, whereas others encompass multiple floristic species, notably the *Brassicaceae* and *Poaceae* families. The results of the physicochemical soil analyses show a slightly alkaline soil with a low variability coefficient noted among the three studied horizons. The electrical conductivity indicates the dominant saline aspect of this soil, with a very high variation among the three profiles. Spatial analysis of organic matter suggests a decrease in organic matter richness as depth increases from the surface layer to deeper layers. In situ water analyses also showed a strongly alkaline pH, relatively high electrical conductivity, and an estimated dissolved oxygen rate. The significant relationships noted between available pH, Electrical conductivity, and dissolved oxygen demonstrate the dynamics of these parameters and the effect of the water quality of the Oum Souid wetland on the transition of elements from one soil layer to another throughout the profile. The spatial distribution of wetlands in desert regions is linked to several environmental factors, mainly water volume, climate, and soil physicochemical characteristics, which affect their ecological diversity. Future studies should monitor seasonal variations and apply remote sensing to assess long-term changes. Given its biodiversity value, the Oum Souid wetland merits consideration for protection under Algeria’s national wetland conservation framework.

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